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Direct Production of High p_t Leptons and Search for Additional Heavy Bosons at 1.8 TeV

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Direct Production of High p_t Leptons and Search for Additional Heavy Bosons at 1.8 TeV

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ABSTRACT

We have studied the production of high p_t electrons and muons and searched for additional heavy charged (W') and neutral (Z') vector bosons. We find no evidence for such bosons and set limits of $M_{W'} > 520$ GeV and $M_{Z'} > 412$ GeV (95% confidence level) assuming Standard Model couplings. The production of high mass electron and muon pairs is consistent with the Standard Model prediction for the Drell-Yan production mechanism. Lower limits of 2.2 TeV and 1.6 TeV (95% confidence level) are set on electron-quark and muon-quark compositeness scale parameters Λ^-_{LL} associated with an effective contact interaction.

1. Introduction

In the Standard Model (SM), high p_t leptons are directly produced in $\bar{p}p$ collisions by the Drell-Yan mechanism.[1] We report here on studies of high p_t electron and muon data collected in $\bar{p}p$ collisions at a center of mass energy of $\sqrt{s} = 1.8$ TeV with the Collider Detector at Fermilab (CDF).[2] For high p_t lepton production, the SM cross section is dominated by the W and Z resonances. Additional heavy vector bosons (W' and Z') are predicted in certain extensions of the SM. For example, additional heavy right handed charged and neutral bosons are predicted in left-right symmetric models, and additional heavy neutral bosons are predicted in non-minimal grand unified models.[3] Stringent, albeit model dependent, indirect experimental mass limits exist from polarized muon decay, neutral current experiments, atomic parity violation and astrophysical observation.[4] Additional heavy vector bosons will be Drell-Yan produced in in $\bar{p}p$ collisions and may be searched for directly in the transverse mass (M_t) and mass (M) distributions of high p_t lepton pairs. Largely model independent limits on cross section times branching ratio (σB) can be obtained with the (reasonable) assumption that the partial width of the vector boson to quarks is proportional

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to $\lambda_{ij}^2 M_V$, where the couplings to quarks, λ_{ij}, and branching ratio to leptons are given in specific models.

2. Event Selection, Backgrounds, and Acceptances

The events for this measurement were collected primarily with inclusive lepton triggers. The efficiency for the electron trigger was measured to be $(97.3 \pm 0.5)\%$ in the transverse energy range $15 \leq E_t \leq 150$ GeV. A jet trigger requiring a large E_t deposition in the calorimeter was also used to ensure high efficiency at high E_t. The efficiency of the muon trigger was measured to be (91 ± 2) % for $p_t > 20$ GeV.

Electron and muon identification efficiencies were measured from W and Z events.[5] For electrons the efficiency was measured to be $(88 \pm 4)\%$. Less stringent requirements were made on the second electron in Z events obtaining an efficiency of $(96 \pm 1)\%$. At very high E_t, these efficiencies degrade due to brehmstraahlung and shower leakage. The former effect was calculated using a radiative Monte Carlo (MC) technique, while the later was extrapolated from measurements with test beam electrons. The efficiency degrades by 15% at 250 GeV. The muon identification efficiency was measured to be (82 ± 7) % for $p_t > 20$ GeV.

The primary backgrounds to directly produced high p_t leptons arise from jets which can either fake leptons or produce indirect leptons from conversions (electrons), K, π decays (muons), and heavy flavor decays. These backgrounds are characterized by their proximity to other high p_t particles and energy flow and can be measured in the data. Additional backgrounds for W events ($W \rightarrow \tau\nu$,Z) and for Z events ($Z \rightarrow \tau\tau$) are calculated from MC. For dimuon events, residual cosmic ray background is estimated from scanning. All of these backgrounds peak at low M_t and M and are negligible above the W and Z resonance peaks.

The acceptance for Drell-Yan events rises at high M_t, M as the events are more centrally produced. The total acceptance at 200 GeV for W' (Z') events, including kinematic, fiducial, and event selection, is calculated to be 48% (51%) for electrons and 28% (24%) for muons. CDF has measured σB for W and Z production and decay to both electrons and muons and found them in excellent agreement with the $\mathcal{O}(\alpha_s)$ QCD prediction.[5]

3. W' Limit

The M_t distribution resulting from the W and a W' is calculated using a MC technique incorporating the W' p_t distribution[6] and a model of the missing E_t resolution based on a full detector simulation. The highest M_t events observed are at 185 GeV (electron) and 205 GeV (muon). To search for the W', a maximum likelihood fit of the data to the W plus W' transverse mass distributions is made. The 95 % confidence level (CL) limit on σB as a function of transverse mass is shown in figure 1. The limit includes systematic uncertainties ($\sim 9\%$) due to M_t shape (W' p_t), and rate (luminosity, efficiency, and acceptance). Also shown is σB for a W' with standard model couplings. We find, for a W' with standard model couplings, $M_{W'} > 490$

GeV (electrons), 435 GeV (muons) and 520 GeV (combined) at 95% CL. Previous direct searches set a lower limit of 220 GeV at 90% CL.[7] The limit on σB applies to the extent that the right-handed neutrino accompanying the observed lepton is light ($\lesssim$ 15 GeV) and stable. It is independent of the W' couplings to leptons and quarks.

4. Z' Limit

The lepton pair mass distribution above 30 GeV is measured to be in excellent agreement with the SM expectation, taking into account efficiency, acceptance, and resolution effects. In particular, 9 electron and 2 muon events are observed above an effective mass of 110 GeV corresponding to an integrated cross section of 4 ± 1 pb, consistent with the Drell-Yan expectation of 4 pb. The highest mass events are 189 GeV (electron) and 155 GeV (muon). The 95 % CL limit on σB as a function of mass is shown in figure 2. The limit includes systematic uncertainties ($\sim$ 10%) due to luminosity, efficiency, acceptance, and QCD corrections. Also shown is σB for a Z' with standard model couplings. We find, for a Z' with standard model couplings, $M_{Z'} > 387$ GeV (electrons), 327 GeV (muons) at 95% CL. By combining the electron and muon data we obtain a preliminary lower limit on the Z' mass of 412 GeV at 95% CL. Previous direct searches set a lower limit of 180 GeV at 90% CL.[7] The σB limit is insensitive to assumptions on the width and is independent of the Z' coupling to quarks, making it valid for a large class of models down to masses approaching the Z mass.

5. Compositeness

If leptons and quarks are composite particles that share consituents, an effective (contact) lepton-quark interaction arises causing a flattening of the dilepton mass distribution at high mass.[8] Based on the absence of electron events with $M > 200$ GeV, we place limits on the scale of such an effective interaction. We find $\Lambda^-_{LL} > 2.2$ TeV and $\Lambda^+_{LL} > 1.7$ TeV at 95 % CL, where the scale Λ corresponds to a left-left electron-quark coupling, and the $-(+)$ sign corresponds to constructive (destructive) interference with the dominant u quark contribution. Similarly, for muons we set preliminary limits on a muon-quark compositeness scale of $\Lambda^-_{LL} > 1.6$ TeV and $\Lambda^+_{LL} >$ 1.4 TeV at 95 % CL.

6. Prospects

Table 1 tabulates prospective limits for $M_{W'}$, $M_{Z'}$, and lepton-quark compositeness scale Λ^-_{LL} in future high luminosity data sets collected with CDF. The $M_{W'}$ and $M_{Z'}$ limits include electron and muon modes, and are calculated assuming constant efficiency, a 20 % systematic uncertainty, and HMRS(B) parton distribution functions. The column labled M_{SM} refers to the mass where one half event is expected with lepton pair mass $M > M_{SM}$ in the SM. The projected limits on Λ^-_{LL} assume no

Prospective Limits (TeV) 95 % CL

L pb^{-1}	$M_{W'}$	$M_{Z'}$	M_{SM}	$\Lambda^-_{LL}(ql)$
25	.68	.59	.33	3.0
100	.79	.71	.43	3.7
500	.88	.84	.56	4.5
1000	.92	.90	.62	4.8

events are observed above this mass, and that the efficiency is constant up to 1 TeV. These projected limits also include a 20 % systematic uncertainty and use HMRS(B) distribution functions. Our anticipated sensitivity to lepton-quark compositeness is comparable to that expected from HERA.[9]

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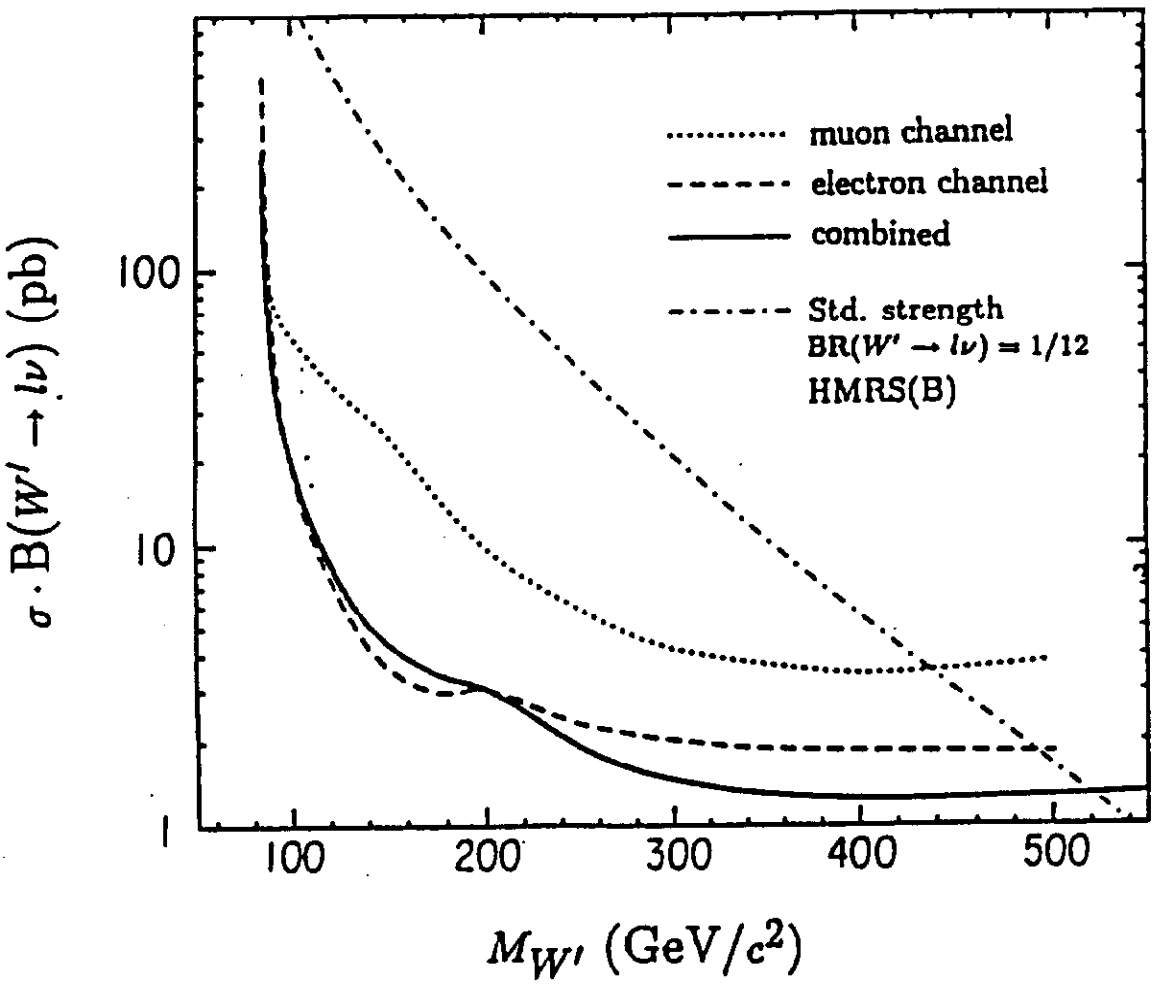

Fig. 1 - The 95% C.L. limits on σB for $W' \to \mu\nu$ (dots), $W' \to e\nu$ (dashes), and combined (solid). Also shown (dot-dashed) is the predicted value, assuming standard-strength couplings to quarks and a branching ratio of 1/12 to each lepton family.

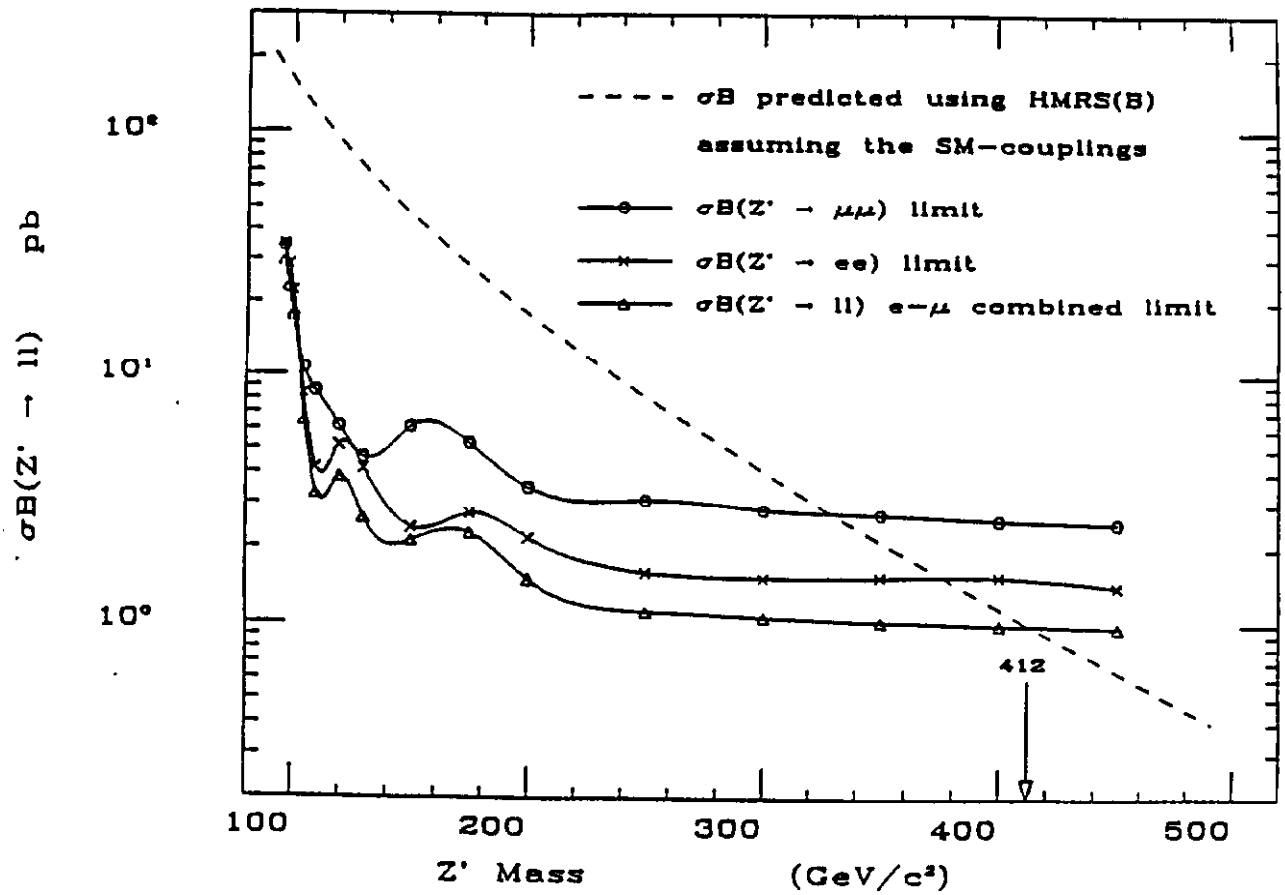

Fig. 2 - The 95% C.L. limit on σB for Z' production from the muon (open circles), electron (crosses), and combined modes (triangles). The dashed line is the prediction of σB for a Z' assuming SM-couplings and using the HMRS(B) parton distribution functions.